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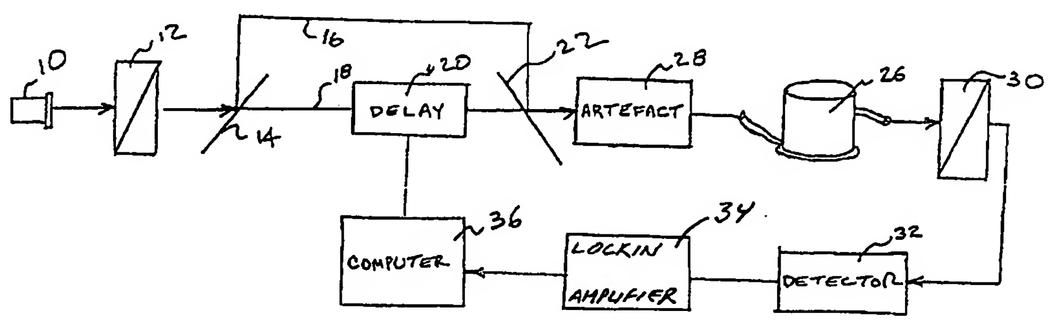

(57) Abstract

A method is provided for high resolution measurement of Polarization Mode Dispersion (PMD) of an optic fiber (26), comprising the steps of: providing a Polarization Mode Dispersion measuring instrument with a light source (10); providing a test fiber (26); arranging the artefact (28) having a stable known Polarization Mode Dispersion value in series with the test fiber (26); transmitting light from the light source (10) through the artefact (28) and the test fiber (26); measuring a biased Polarization Mode Dispersion value with the Polarization Mode Dispersion measuring instrument biased away from a zero Polarization Mode Dispersion value; and determining the Polarization Mode Dispersion of the optic fiber from the biased measured Polarization Mode Dispersion value.

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Measurement of Polarization Mode Dispersion

This is a divisional of copending patent application serial no. 08/445,320, filed May 19, 1995, hereby incorporated by reference.

FIELD OF INVENTION

The present invention relates to a method for testing optical fibers, and more particularly to a method for measuring at high resolution Polarization Mode Dispersion (PMD) values in single mode optical fibers.

BACKGROUND OF THE INVENTION

Single mode optical fibers are used to transmit large quantities of information over significant distances. In order to preserve the integrity of such transmissions, it is desirable to eliminate distortion. It is impossible, however, to remove all forms of distortion from transmissive media. Therefore, it is necessary to measure the distortion, either to determine the suitability of a transmissive medium's maximum information capacity, or to determine the most satisfactory manner of handling the distortion. For a fiber optic communications system, the bit-error rate is the most significant specification for determining the information carrying capacity of the system. The bit-error rate is

increased by, among other factors, the pulse broadening caused by dispersion in a fiber. Use of a single mode fiber eliminates modal dispersion, but not chromatic dispersion or Polarization Mode Dispersion, which is a bandwidth limiting effect that is present to some degree in all single mode fibers that are suitable for optical transmissions. It is, therefore, a potential source of signal distortion in optical communications systems.

In general, Polarization Mode Dispersion measurement instruments are known in the art, and particularly defined in draft standards of the Telecommunications Industries Association, headquartered in Arlington, Virginia. These standards include Fiber Optic Test Procedure FOTP-113 for Polarization-Mode Dispersion Measurement for Single-Mode Optical Fibers by Wavelength Scanning, FOTP-122 for Polarization Mode Dispersion Measurement for Single-Mode Optical Fibers by Jones Matrix Eigenanalysis, and FOTP-124 for Polarization-Mode Dispersion Measurement for Single-Mode Optical Fibers by Interferometric Method. The detailed operation and procedure of the Polarization Mode Dispersion measurement instrument is described in these standards.

Also, a particular prior art circuit means is described in U.S. Patent No. 4,750,833, issued to R. Jones, hereby incorporated by reference. Polarization Mode Dispersion measurement instruments include cycle counting, time pulse methods, relative phase methods or Jones Matrix Eigenanalysis, as discussed in more detail below. For example, Jones

describes a known method for measuring dispersion in optical fibers. In particular, Jones describes a relative-phase method and apparatus for measuring transmissive dispersion, such as chromatic or polarization dispersion. A light source modulated at a first frequency is synchronously varied at a lower frequency back and forth to and from a first and a second value of a transmission parameter, e.g. source wavelength or polarization state. Relative phases of the first modulation signal and the light transmitted through the fiber under test are measured by a phase detector. A lock-in amplifier compares the phase detector output to the lower frequency signal to provide a direct current output indicative of dispersion.

Another method for measuring dispersion in optical fibers measures time differences. The Jones Matrix Eigenanalysis method measures DGDΔλ as a function of wavelength, where DGD is known as a differential group delay, and PMD is expressed as $< \Delta\tau >_{\lambda}$. The relative-phase method and apparatus described in Jones proved to be superior in resolution than the method for measuring time differences.

Other known methods of measuring Polarization Mode Dispersion in optical fibers include Interferometry, Jones Matrix Eigenanalysis, the Wavelength Scanning (WS) cycle counting metnod, and the WS Fourier method. Interferometry uses the time domain to employ a low-coherence light source and a Michelson or Mach-Zehnder Interferometer to observe output in the form of the autocorrelation function of the time

distribution, and the Polarization Mode Dispersion of the fiber may be obtained from this data. Interferometry is limited at the low end by the coherence time, typically 0.15 picoseconds, of the broadband source used.

Jones Matrix Eigenanalysis uses a polarimetric determination of the instantaneous polarization transmission behavior, in the form of a Jones matrix with two eigenstates called Principal States of Polarization (PSP). By measuring the wavelength variation of the Jones matrix and hence the PSPs, the different delays between PSPs may be determined. The delay is averaged over a specific wavelength scan to establish the fiber Polarization Mode Dispersion value. Jones Matrix Eigenanalysis is limited by polarimetric accuracy and resolution to 0.01 picoseconds.

The WS cycle counting and the WS Fourier methods both use a light power transmission through the fiber using a linearly polarized source and a polarization analyzer before the light detector. The fiber gives rise to an oscillation pattern whose oscillation frequency is related to Polarization Mode Dispersion. In the WS cycle counting method, the number of complete oscillations in a given wavelength interval is counted to determine Polarization Mode Dispersion. The WS cycle counting method is limited to a minimum of three cycles in the wavelength scan, typically 0.09 picoseconds. In the WS Fourier method, however, wavelength scanning Polarization Mode Dispersion is determined by a frequency analysis technique on the oscillation pattern based on a Fourier transform. The

Fourier method is limited to a minimum of one cycle in the wavelength scan used, typically 0.03 picoseconds.

One important disadvantage of the known prior art is that the determination of the Polarization Mode Dispersion value is adversely influenced by spurious responses that combine with measured results to distort the Polarization Mode Dispersion value.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a method for measuring with higher resolution Polarization Mode Dispersion values below 0.1 picoseconds, useful, e.g. with fibers used for transmission systems operating 5 Gigabits per second or above.

It is also an object of the present invention to provide a method for measuring Polarization Mode Dispersion values between 0.01 picoseconds and 0.1 picoseconds for use, e.g., with WS Fourier and Interferometry methods.

It is also an object of the present invention to use a birefringent or wavelength specific artefact to bias Polarization Mode Dispersion away from zero, resulting in a broadened Polarization Mode Dispersion peak of the artefact, in order to obtain improved detection and determination of very low Polarization Mode Dispersion levels in optical fibers.

It is also an object of the present invention to determine the Polarization Mode Dispersion of an optical fiber

by appropriate data processing of the broadened artefact peak.

It is also an object of the present invention to provide a method for calibrating wavelength scanning Polarization Mode Dispersion instruments using a birefringent or wavelength selective device.

In accordance with the present invention, a method is provided for improving the measurement of Polarization Mode Dispersion by incorporating an artefact with a stable known Polarization Mode Dispersion value in a Polarization Mode Dispersion measuring instrument, and having a light source transmit light serially through an optic fiber to be tested and the artefact. The artefact biases a total Polarization Mode Dispersion measured by the Polarization Mode Dispersion measuring instrument away from zero, thus removing the undesirable influence of any spurious (near-zero) Polarization Mode Dispersion response from the measurement. The Polarization Mode Dispersion of the optic fiber may then be accurately determined by appropriate data processing of the measured Polarization Mode Dispersion. The artefact may also be used to calibrate a wavelength scanning Polarization Mode Dispersion instrument.

The invention enables a high resolution measurement of Polarization Mode Dispersion with at least one order of magnitude higher, and possibly two orders of magnitude higher, than that achievable with the prior art relative phase or time measurement system.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention, both as to its organization and manner of operation, may be further understood by reference to a drawing (not drawn to scale) which includes Figures 1-4 taken in connection with the following description.

Figure 1 is a block diagrammatic representation of a Polarization Mode Dispersion measurement instrument in accordance with the present invention utilizing a Mach-Zehnder interferometer.

Figure 2 is a block diagrammatic representation of a Polarization Mode Dispersion measurement instrument in accordance with another embodiment of the present invention suitable for use with wavelength scanning Fourier analysis (WS Fourier).

Figure 3a is a graph of time versus Polarization Mode Dispersion value for a prior art Polarization Mode Dispersion measurement instrument.

Figure 3b is a graph of time versus Polarization Mode Dispersion value for a Polarization Mode Dispersion measurement instrument of the present invention.

Figure 4 is a block diagram of an application of the present invention to calibrate a Polarization Mode Dispersion instrument.

DESCRIPTION OF THE BEST MODE OF THE INVENTION

Figures 1 and 2 are block diagrams of two Polarization Mode Dispersion measurement instruments for high resolution, polarization dispersion measurement, which are the subject of the present invention. Figure 1 shows one Polarization Mode Dispersion measurement instrument using an interferometric measurement technique, while Figure 2 shows another Polarization Mode Dispersion measurement instrument using a wavelength scanning Fourier analysis (WS Fourier) technique.

In Figure 1, the Polarization Mode Dispersion measurement instrument has a light source 10 which may be either a light emitting diode (LED), as shown, or in an alternative embodiment, a superfluorescent light source (not shown). The Polarization Mode Dispersion measurement instrument has a polarizer 12 that responds to light coming from an output of the light source 10, for providing polarized light. A beam splitter 14 connected to the polarizer 12 divides the polarized light for transmission in a first path 16 and a second path 18. The second path 18 includes a delay line 20 for delaying the transmission of light. The delay line 20 can be adjusted to alter a relative optical delay between the first and second paths 16 and 18. As shown, the delay line 20 is a Mach-Zehnder interferometer, which is known in the art. A beam splitter 22 receives light transmitted along the first and second paths 18 and 20 and delivers it to an artefact 28.

The artefact 28 is a device which produces a known, stable Polarization Mode Dispersion. The artefact 28 will

assure that the Polarization Mode Dispersion measurement instrument will have a known interference peak level at a particular time value T, as best shown in Figure 3b. In the embodiment shown in Figure 1, the artefact 28 is a birefringent device, which may be a birefringent waveplate, birefringent fiber or other birefringent device. The time T is the time difference between the fast and slow polarization modes, or simply the Polarization Mode Dispersion of the artefact 28. In the present invention, the artefact 28 serves to bias the total Polarization Mode Dispersion measured by the instrument away from zero, removing the influence of any spurious (near-zero) Polarization Mode Dispersion response from the measurement, as shown in Figure 3b.

A test fiber 26 receives light from an output of the artefact 28. The connection between the artefact 28 and the test fiber 26 is known in the art, and may include a lens system, a butt splice to a single mode fiber pigtail or an index-matched coupling. However, the scope of the invention is not intended to be limited to any particular series arrangement between the artefact 28 and the test fiber 26. For example, as shown, the artefact 28 is arranged before the test fiber 26 in Figure 1, while in Figure 2, the artefact 60 is arranged after the test fiber 56. Such a construction could also be incorporated in accordance with these teachings in a Michelson interferometer.

An output of the fiber 26 is delivered to an analyzer 30 that observes interferences between principal orthogonal

states of polarization, and provides an analyzed signal to a detector 32, that represents polarization states versus power. The detector 32 converts an optical signal to an electrical signal. In an alternative approach, a polarimeter may be used. A lock-in amplifier 34 is a synchronized phase and volt meter which is used to demodulate chopped or modulated optical signals for signal processing. A computer 36 provides electronic signal processing and apparatus control functions. The interference signature versus the setting of the delay line 20 is determined and stored using a standard computer 36.

Figure 2 shows an alternative embodiment of the present invention in which the Polarization Mode Dispersion measurement instrument has an artefact 60 coupled to an output of a test fiber 56. In Figure 2, a light source 50 delivers light to a polarizer 52 for coupling through a splice 54 to a fiber under test 56. A splice 58 couples an output of the test fiber 56 to the artefact 60. An analyzer 62 analyses the light polarization state, and an optical spectrum analyzer or monochromator 64 allows the polarization transmission versus optical wavelength to be measured. The computer 68 performs a Fourier analysis and apparatus control functions, and Polarization Mode Dispersion calculations.

The artefact 60 produces a known, stable Polarization Mode Dispersion. It will assure that the Polarization Mode Dispersion measurement output will have a known peak level at a particular time value T. In the embodiment in Figure 2, the artefact 60 may be a birefringent device, which may be a

birefringent waveplate, birefringent fiber or other birefringent device. The time T is the time difference between the fast and slow polarization modes, or simply the Polarization Mode Dispersion of the artefact 60. In alternative embodiments, the artefact 60 may also be a reflective or transmissive device which provides a known stable sinusoidal response of power versus wavelength indicative of the insertion loss spectrum of the artefact. An example of either artefact 60 is a Fabry-Perot etalon, including an interferometer. The sinusoidal response of power versus wavelength will give an apparent Polarization Mode Dispersion peak at time T, corresponding to the known, stable insertion loss spectrum of the artefact.

A comparison of the results of the graphs in Figures 3a and 3b illustrates how the addition of the artefact 28 (Figure 1) or the artefact 60 (Figure 2) of the present invention greatly improves the resolution of Polarization Mode Dispersion measurement instruments shown in Figures 1 and 2. In both Figures 3a and 3b, the abscissa is time, and the ordinate is Polarization Mode Dispersion value. As shown, spurious responses are illustrated in dotted lines, and measured results are illustrated in solid lines. As Polarization Mode Dispersion values approach zero, there are many effects that can produce a greater error than the value of the Polarization Mode Dispersion. Spurious responses are due to optical losses and other optical imperfections, or source coherence. Such responses provide results that combine

with a low level of Polarization Mode Dispersion and distort it. As shown in Figure 3a, in a prior art Polarization Mode Dispersion measurement instrument (not having the artefact 28 or 60), the width, e.g. Root Mean Square width, of the signature (solid line) is calculated to determine Polarization Mode Dispersion of the fiber under test. However, the spurious responses have combined with the measured results to distort the Polarization Mode Dispersion value.

In contrast, as shown in Figure 3b in the Polarization Mode Dispersion measurement instrument of the present invention, the basic Polarization Mode Dispersion signature is transposed by the artefact 28 or 60 from zero to time T. The spurious effects do not interact with the measured dispersion. As shown in Figure 3b, the spurious responses do not affect measurement of Polarization Mode Dispersion during a calculation of the width, e.g. Root Mean Square width, of the measured peak.

Figure 4 shows a calibration of a Polarization Mode Dispersion in accordance with the present invention. A test fiber is not included in the light path. An artefact 106 is included, which receives light transmitted from a broadband source 100 through a polarizer 102 coupled to a splice 104. A splice 108 couples the output of the artefact 106 to an analyzer 110 whose output is analyzed by a measuring means 112 comprising an optical spectrum analyzer or monochromator and computation means 114 operating in accordance with the principles described with respect to Figure 2. The artefact

104 will bias the measured Polarization Mode Dispersion away from zero. The measured Polarization Mode Dispersion is compared to the known Polarization Mode Dispersion value of the artefact 104. The result of this can be viewed in a number of ways. The system of Figure 4 is thus calibrated so that a particular electrical output corresponds to the known value of the artefact 104. Further, this operation provides an update to factory calibration or periodic field calibration. This method is applicable to a WS Fourier method and WS cycle counting measuring methods, discussed above.

Additionally, there are further calibration techniques available for wavelength scanning methods, which may use wavelength transmissive or reflective devices for an artefact. In such a case, the Polarization Mode Dispersion apparatus produces a Polarization Mode Dispersion signature at time T equivalent to the known, stable insertion loss spectrum of the artefact in accordance with the principles described with respect to Figure 2. The above teachings will enable those skilled in the art to provide many different embodiments of high resolution measuring means which can employ wavelength transmissive devices for the artefact.

It will thus be seen that the objects set forth above, and those made apparent from the preceding description, are efficiently attained and, since certain changes may be made in the above construction without departing from the scope of the invention, it is intended that all matter contained in the above description or shown in the accompanying drawings shall

be interpreted as illustrative and not in a limiting sense.

It is also to be understood that the following claims are intended to cover all of the generic and specific features of the invention herein described and all statements of the scope of the invention which, as a matter of language, might be said to fall therebetween.

WHAT I CLAIM IS:

1. A method for high resolution measurement of a Polarization Mode Dispersion of an optic fiber, comprising the steps of:

providing a Polarization Mode Dispersion measuring instrument with a light source;

providing a test fiber;

arranging the artefact having a stable known Polarization Mode Dispersion value in series with the test fiber;

transmitting light from the light source through the artefact and the test fiber;

measuring a biased Polarization Mode Dispersion value with the Polarization Mode Dispersion measuring instrument biased away from a zero Polarization Mode Dispersion value; and

determining the Polarization Mode Dispersion of the optic fiber from the biased measured Polarization Mode Dispersion value.

2. The method according to claim 1, wherein the method includes providing the Polarization Mode Dispersion measuring instrument that utilizes interferometry.

3. The method according to claim 2, wherein the artefact is a birefringent device.

4. The method according to claim 3, wherein the

birefringent device is a birefringent waveplate or birefringent fiber.

5. The method according to claim 1, wherein the Polarization Mode Dispersion measuring instrument utilizes a Wavelength Scanning Fourier method.

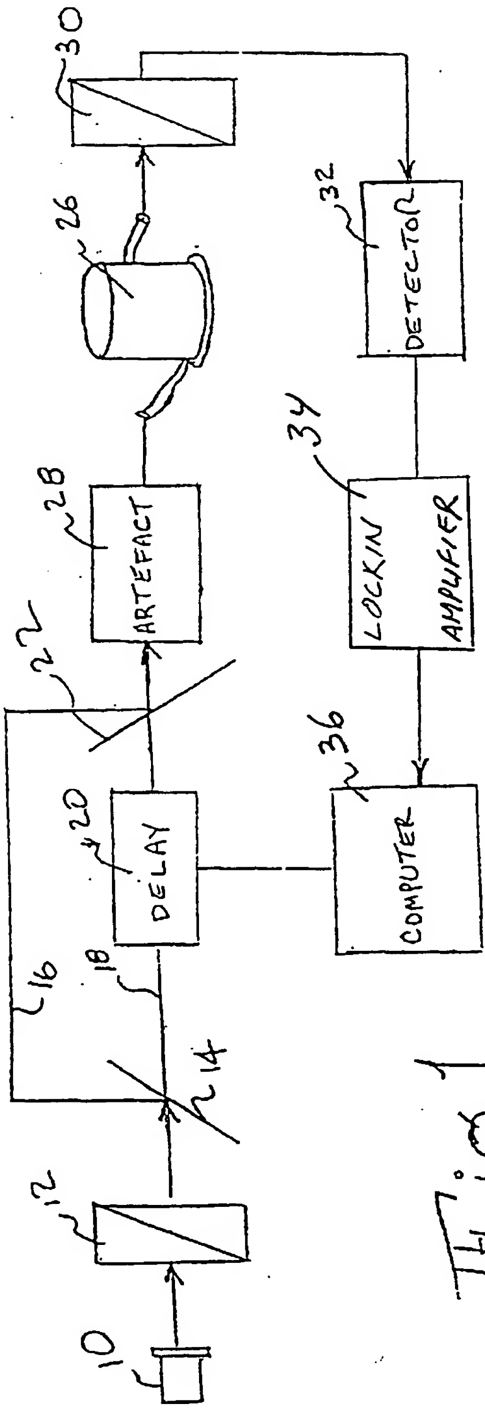
6. The method according to claim 5, wherein the artefact is a birefringent device.

7. The method according to claim 5, wherein the birefringent device is a birefringent waveplate or birefringent fiber.

8. The method according to claim 5, wherein the artefact is a wavelength-dependent transmissive device.

9. The method according to claim 5, wherein the artefact is a wavelength-dependent reflective device.

10. The method according to claim 1, wherein the step of providing an artefact further comprises the step of providing an artefact having either known wavelength-dependent transmissive characteristics or known wavelength-dependent reflective characteristics.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COMPUTER
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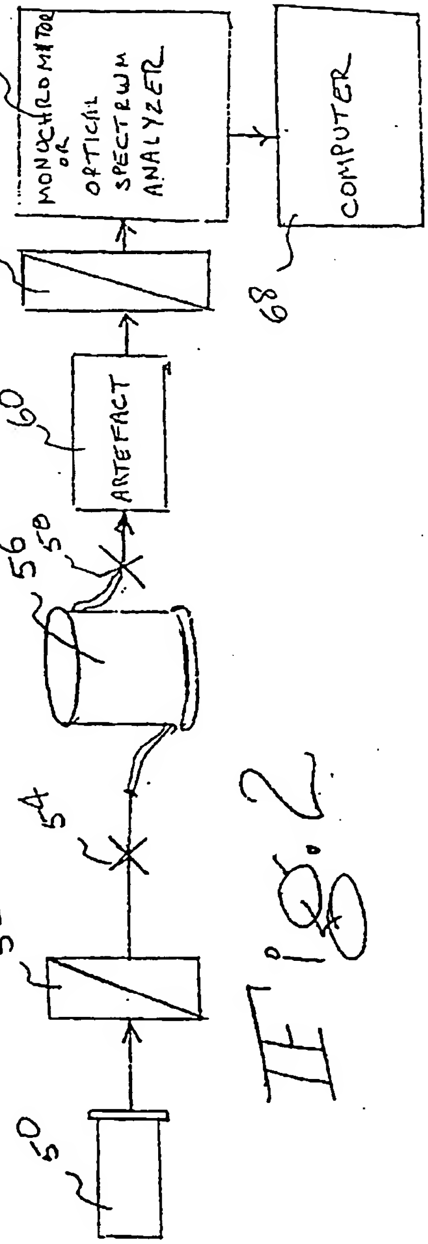
Fig. 1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MONOCHROMATOR OR OPTICAL SPECTRUM ANALYZER
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COMPUTER
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Fig. 2

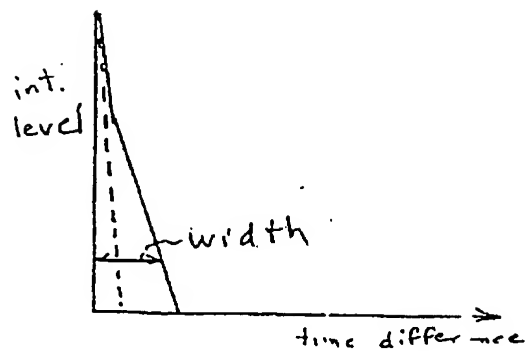

Fig. 3a

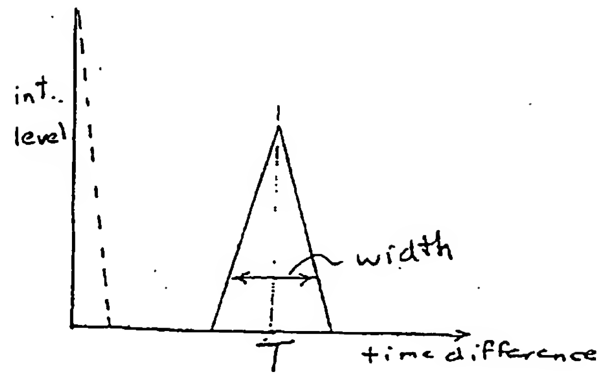

Fig. 3b

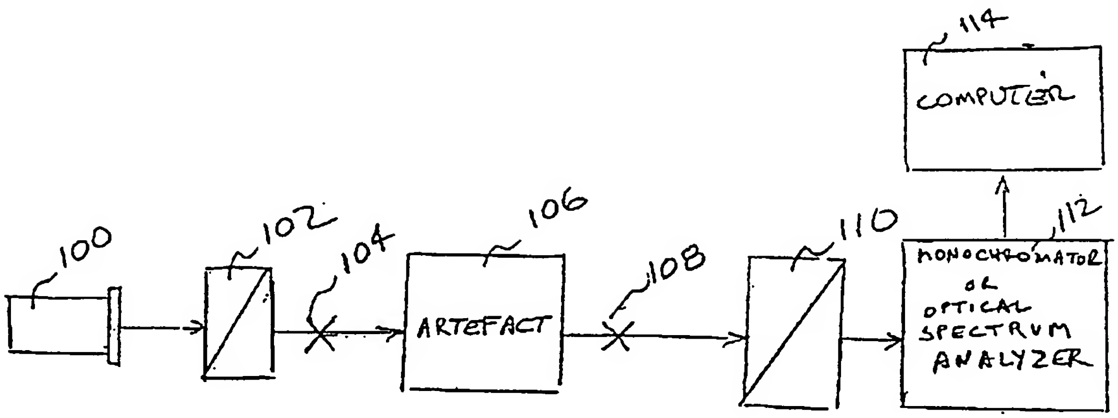

Fig. 4